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Notes on Wastage of Non-Parasitic Origin in Stored Apples.

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1. Introduction.

During the past three seasons (1927-30), investigations have been made into the nature, causes, and control of wastage of non-parasitic origin in apples, particularly those in storage. In the main, the results obtained have arisen out of the investigation of bitter-pit and associated diseases and not as planned attacks on the specific defects. They are published, not as completed contributions to the problem, but in the hope that they will stimulate investigations into the causes of wastage from rather a new aspect. The outstanding result of our work has been to lay weight on the importance of the pre-storage condition of the fruit in relation to defects developed in store. Many factors determine the storage life and condition of fruit. Our work has led us to the conclusion that unless the pre-storage condition of the fruit is known, the results of storage experiments may be misleading. Further, while some defects may be modified and reduced by storage control, they can in many cases be largely avoided by using fruit in a condition naturally resistant to their onset.

The present paper summarizes our knowledge of breakdown, Jonathan spot, superficial scald, &c., and may be regarded as a continuation of a paper entitled "The Present Position of the Bitter-pit Problem in Australia," dealing with bitter-pit and cork, and submitted to the Conference of Empire Horticulturists held in August of this year. Only a selection of the available facts is given, but it is hoped at a later date to publish the data in full.

Early in the investigations, it was found that as great a confusion existed as to the nomenclature and identity of the several storage defects here dealt with as had already been found to be the case with bitter-pit (5). It therefore became necessary, as a first step, to define them clearly. As with bitter-pit, the method adopted has been to relate each, as it was found in storage tests to what appeared to be the principal causative factor in each case.

Difference in response to similar conditions is regarded as distinguishing different defects, though for convenience those with similar symptoms have been grouped together. Working on this basis, it has been possible to define the diseases with considerable accuracy. Difficulty has been experienced at times in utilizing the published results of other workers because of doubts as to the identity of the diseases on which they worked. This has also led to a considerable uncertainty as to the part played by the different defects in the several States and in Australian apples as a whole. Almost invariably, definite information as to the condition of the fruit when stored has been lacking, yet this, in our experience, is of the utmost importance in the study of storage defects. The evidence is clear

that storage defects must be, at least primarily, investigated in the district or country in which the fruit is grown. To illustrate this point, water-core and bitter-pit have both been found to be very potent causes of breakdown. As the former is in the fruit when stored and the latter occurs only in immature fruit, it is clear that breakdown from these causes should, if possible, be controlled by the reduction of water-core or of pit-liability in the fruit before storing. In other words, the first line of attack should be towards removing the primary causes of wastage. When this is not possible, it may be possible to reduce the loss by controlled storage conditions.

2. Breakdown.

The defects known as breakdown, flesh collapse, physiological decay, brown heart, &c., form a group with a general similarity of symptoms and one which causes important losses in both locally-stored and exported Australian apples. In exported fruit in particular, it is perhaps the most serious cause of wastage, though in some varieties bitter-pit may be more important, especially when the fruit is first unloaded. Exported fruit, to be successful, should keep in good market condition and with a wastage not exceeding 10 per cent. for about three weeks after it is discharged. It is during this period between unloading and retail distribution that breakdown becomes important. Wastage under normal export conditions from this cause may at times reach 10 to 50 per cent. in susceptible varieties such as Jonathan, Cox's Orange Pippin, and Ribston Pippin (according to an unpublished report by Dr. Barker, of the Low Temperature Research Station at Cambridge). From trade reports, the loss appears to be most severe in the early and, to a lesser extent, in the later part of the export season for each susceptible variety. Loss in locally-stored fruit is occasionally severe, but usually after relatively long storage periods. It is rare within the time taken to export and market fruit overseas which seldom exceeds and is usually under twelve weeks.

Though several forms of breakdown have been recognized by workers in other parts of the world, the forms occurring in Australian fruit have never been clearly determined.

As we use the term, breakdown, which is not parasitic in origin, is a browning and death of the tissues of the core or cortex. It may, and usually does, eventually affect the skin, and is usually, but not always, progressive, finally involving the whole of an affected fruit. There are two general types, one representing the normal end of life, i.e., death from senility in the absence of other defects, and the other a pathological condition induced by storage conditions in fruits which are predisposed by varietal characters and by defects of maturity and condition.

The following classification is proposed for the forms described in literature or recognized by us as distinct:—

(*a*) Caused by normal senility.

1. Over-maturity breakdown.

(*b*) Caused by immaturity at picking time.

2. Immaturity breakdown.

3. Bitter-pit breakdown.

(*c*) Caused primarily by temperatures below 37°.

4. Low temperature breakdown.
5. Deep scald.
6. Freezing breakdown.

(*d*) Caused by water-core.

7. Water-core breakdown.

(*e*) Caused by abnormal storage atmospheres.

8. Gas breakdown (brown heart).

(*f*) Caused by mechanical injury to the tissues.

9. Bruise breakdown.

It is not contended that all these forms are distinct in their chemical history, but that each has its origin in a particular and specific set of conditions. That being accepted, it becomes obvious that the most effective means of control is, if possible, to alter or remove the fundamental causal conditions.

Before proceeding to a discussion of the different forms of breakdown, it is necessary to define the terms mature and immature, as difficulty has been experienced in deciding what they mean to other workers. As used by us, mature for picking means that sound apples, if picked, will ripen normally and keep for a period reasonable for the variety under, and after, normal cold storage conditions. Immature apples will not, if picked, ripen normally in respect to quality and condition. Over-mature apples will ripen normally, but will not maintain their condition for a period reasonably long enough for economic purposes. By normal storage conditions are meant the conditions usually implied in commercial cold storage, i.e., a temperature from 33°–38°, a relative humidity around 80 per cent., and reasonable ventilation. The normal temperature varies somewhat in different apple areas, in some a mean of 33°–34° being general and in others about 37°. The reasonable length of storage also varies with the variety and the district in which it is grown, this, like the temperature, being largely decided by commercial experience. The reasonable period for apples to keep after storage is about three weeks for both locally-stored and exported fruit to allow for retail distribution. Picking maturity has been found by us to represent a stage in the maturation of an apple which varies with the variety and, most probably, with the conditions under which it has been grown. Part of the evidence dealing with Cleopatra has been published(5). In bitter-pit-liable varieties, picking maturity coincides very closely with the degree of maturity at which liability to pit disappears.

1. Over-maturity Breakdown.

This form has received many names, including mealy and inherent breakdown, senile or physiological decay, &c. It may be regarded as the normal end of life, in the absence of fungal or bacterial rots, of sound fruits of many varieties. Commercially, it is a storage defect, though it may develop in fruit on the tree if picking is too long delayed. Early and early mid-season varieties, that is, those which pass through their maturation period very rapidly, are particularly subject. They are typically soft-fleshed varieties and include the Jonathan, Cox's Orange Pippin, Gravenstein, &c. The

more mature the fruit when stored and the higher the storage temperature, the more rapid is the onset of breakdown. Large fruits are more susceptible than smaller, and those from light crops than from heavy. Second-crop apples, such as may set on growths of the same season, are less liable than the main crop from the same trees. If stored in an immature condition, the fruit may shrivel or develop breakdowns of the immaturity and bitter-pit type.

Over-maturity breakdown has generally been considered to be the cause of the "sleepy" or over-ripe fruit found in varieties like the Jonathan when exported or submitted for export in the latter part of their seasons. It has also been considered the principal factor in limiting the storage life of susceptible varieties, the reason, for instance why Jonathans in Western Australia can rarely be held with safety after September. While there is little doubt that over-maturity has been a factor in the cases stated, the fact remains that there is no definite evidence to that effect. The absence in most cases of a knowledge of the pre-storage condition of the fruit, except as indicated by its external appearance, leaves it open to possibility that factors other than over-maturity may have been operating. Certainly, in our experiments, over-maturity *per se* has not been an important factor in the keeping quality of the fruit. Indeed our experience with commercial fruit suggests that over-maturity is far from being the most important cause of breakdown in Western Australian apples. In Jonathans, at least, water-core is apparently much more important. The fact that water-core tends to increase with ripeness in this variety, and that it is impossible in most cases to recognize its presence in the fruit, has led to this cause of subsequent breakdown being overlooked. Fruit stored locally or shipped overseas has been reported overripe and rotten (breakdown or rots), although packed in good, firm condition, and stored at reasonably low temperatures. In many cases, the possibility of the fruit being truly overripe has been out of the question. Other factors than over-maturity, such as immaturity, bitter-pit, water-core, &c., must have operated.

The prevention of over-maturity breakdown is obvious. Care should be taken to prevent the fruit becoming overripe for picking either on the tree or in the packing shed. Well-matured fruit should be cold-stored promptly. When exported, it should not be allowed to get heated between the store and the ship, and should be loaded into holds which have been pre-cooled. Large fruits should be avoided, especially from light crops. Fruit should not be held on the tree after picking maturity has been indicated by the colour changes in the non-flushed skin.

2. Immaturity Breakdown.

This name is tentatively proposed for a type of breakdown met in these experiments. Its right to specific standing is somewhat uncertain. On the basis that different responses to the same influences indicate specific differences, the distinction is justified. It may be that it is identical, in part, with low-temperature breakdown (*q.v.*). The latter disease, according to North American and New Zealand experience, consistently increases with the maturity of the fruit when stored. English experience has, on the other hand, shown that the effect of the degree of maturity is variable (9). On the principle already stated we

would consider that factors in addition to low temperature have operated in the English experiments. It is therefore suggested that the two may be separated as follows:—

> Low-temperature breakdown develops at temperatures below about 37° F., its incidence increasing with the maturity of the fruit when stored. Immaturity breakdown decreases with the maturity of the fruit when stored. Its temperature relations are uncertain.

In our experiments it was found in Dunns (Fig. 1), commencing as a core-browning and finally developing as a general breakdown associated with superficial scald. Four pickings at fortnightly intervals in 1929 showed a core-browning after ten weeks at a mean temperature of 36° F. in the first three pickings. The discoloration was so slight as to be of no economic consequence. Duplicate collections were retained in store for 6-7 months, the mean temperature for the second period being 33-34°. When examined eighteen days after removal from store, the following results were obtained:—

Dunns Apples (Karragullen, Western Australia).

Picked.	Percentage Deep Scald.	Percentage Superficial Scald.	Percentage Core-browning.	Percentage Breakdown.
	%	%	%	%
12.2.29 ..	Nil	100	70*	27
26.2.29 ..	Nil	100	Sold and not examined	Not examined
12.3.29 ..	Nil	100	65	29
26.3.29 ..	Nil	11	22	2

* In these articles percentages are given to the nearest integer.

Storage experiments in 1929, lasting ten weeks, showed that the best picking period for quality and freedom from bitter-pit was from the third week of March. The core browning in the last pick in the long stored fruit was economically negligible. The difference in superficial scald was very marked, the fruit of the immature pickings being unsaleable after eighteen days at ordinary temperatures. Even after five days, the difference was marked, and a case ($2\frac{1}{2}$ inches) of the second picking sold at 10s. 6d., as against 11s. 9d. for a case ($2\frac{1}{2}$ inches) of mixed fruit from the third and fourth pickings.

A similar core browning was found in shed-stored (60-90°) Jonathans in 1930, but not in cold-stored fruit, after eight weeks in both lots. It occurred to the extent of 34 per cent. in fruit picked 30th January, 5 per cent. picked 13th February, and nil picked 27th February. In this case the lower humidity in the shed as compared with the cold store may have been a factor.

Occurrences of what might be immaturity breakdown have been recorded by Harrison (7) as a result of experiments with Jonathans in Victoria in 1925. Apples from four different sources were stored from 5-7 months. In three experiments in which the fruit was stored

at different temperatures breakdown decreased with an increase of temperature. In the fourth there was a rise and fall. The figures are given below:—

Jonathan Apples (Victoria).

District.	Percentage Deep Scald.			Percentage Breakdown.		
	32°.	34°.	37°.	32°.	34°.	37°.
	%	%	%	%	%	%
Harcourt ..	11	6	Nil	10	10	4
Hastings ..	3	1	Nil	16	10	Nil
Drouin ..	..	Nil	Nil	..	51	26
Pakenham ..	4	8	Nil	41	51	10

Fruit from two of these sources was picked from the same trees at different periods, with results as under:—

Jonathan Apples (Hastings, Victoria). Stored 7 months at 32°.

Picked.	Percentage Deep Scald.	Percentage Breakdown.
	%	%
10.3.25 ..	15	52
19.3.25 ..	3	25

Jonathan Apples (Harcourt, Victoria). Stored 5-6 months at 32°.

3.3.25 ..	2	Nil
16.3.25 ..	49	37
6.4.25 ..	49	21

In both these cases breakdown declined with the maturity of the fruit. Taking the Hastings and Harcourt fruit, we have breakdown declining, after a certain period, with the maturity of the fruit, and also reduced by an increase of temperature. In the Pakenham and possibly the Drouin fruit the effect of temperature is somewhat different, as there is a rise and then a decline with increasing temperature. It will be noted that, where maturity comes into the experiment, there is an association of deep scald and breakdown, both declining together. Similar Victorian experiments by Adam (1), in 1923, and Adam and Harrison (2), in 1924, gave quite different relations of breakdown to scald and breakdown to temperature, but a similar reduced susceptibility with increasing maturity.

Jonathans (Drouin, Victoria). Stored 6 months.

Picked.	32°.		36°.	
	Percentage Deep Scald.	Percentage Breakdown.	Percentage Deep Scald.	Percentage Breakdown.
	%	%	%	%
20.3.23 ..	85	8	22	68
15.4.23 ..	3	7	1	4

Jonathans (Drouin, Victoria). Picked 7th April, 1924, stored 2½ months.

—	Percentage Deep Scald	Percentage Breakdown.
	%	%
32°	44	Nil
34°	45	Nil
37°	Nil	3
Jonathans (Drouin, Victoria). Picked 31st March, 1924, stored 4 months.		
32°	18	2
37°	5	14

It is obvious that more than one type of breakdown has been involved in these experiments, though in the absence of data as to the pre-storage condition of the fruit it is not possible to identify the forms. Certainly the evidence suggests that neither over-maturity or low temperature by themselves have been responsible, while the likelihood that water-core played a part, at least in some of the experiments, is very strong (see water-core breakdown).

3. Bitter-pit Breakdown.

As bitter-pit is primarily due to the immaturity of the fruit when picked, it follows that bitter-pit breakdown is a type of immaturity breakdown. However, it is quite distinct from the form we have called immaturity breakdown. The latter tends to commence as a browning of the core, while the former starts in the cortex, usually close to bitter-pit lesions.

The association of bitter-pit and breakdown has been noted frequently in Australian apples in Europe (6), particularly in Cox's Orange Pippin, Ribston Pippin, and Cleopatra, all very pit-liable varieties. It has also been marked in our experiments, particularly with Cox's Orange Pippin, Cleopatra, and Jonathan (Plate 1, Fig. 2). It not infrequently happens that some non-pitted apples in groups having a high percentage of pitted fruits develop breakdown, though in a smaller proportion than the pitted fruit. It is believed that most of this breakdown of otherwise apparently sound fruit is due to the effect of pit-causing conditions on the tissues, though they have not been severe enough to actually cause death and pitting. Bitter-pit breakdown occurs more in cold-stored than shed-stored fruit, and usually the bulk of it develops after the fruit is removed from store. The following are some instances of its occurrence:—

Cox's Orange Pippins (Western Australia). Cold stored 20th February, 1929, removed to room 10th April, 1929, examined 30th April, 1929.

Size.	Percentage Bitter Pit only.	Percentage Pit and Breakdown.	Percentage Breakdown only.
	%	%	%
2 inches ..	69	1	Nil
2¼ inches ..	50	5	Nil
2½ inches ..	57	39	Nil

Jonathan (Western Australia, 1929, returned from England).

Size.	Percentage Bitter Pit only.	Percentage Pit and Breakdown.	Percentage Breakdown only.
2¾ inches ..	11	84	2
3 inches ..	9	83	1

Cleopatra (Western Australia, 1929, returned from England).

2¼ inches ..	82	14	Nil
2¾ inches ..	88	10	Nil
3 inches ..	89	7	Nil

Jonathan (Karragullen, Western Australia). Eight weeks 30-36° F., and three weeks 50-90° F.

Picked.	Percentage Pit only.	Percentage Pit and Breakdown.
	%	%
30.1.30 ..	4	1
13.2.30 ..	Nil	2
27.2.30 ..	Nil	Nil

Jonathan (Karragullen, Western Australia). Eight weeks 50-90° F. in shed.

30.1.30 ..	6	Nil
13.2.30 ..	4	7
27.2.30 ..	Nil	Nil

The absence of breakdown in the pitted fruit of the first picking in the shed-stored fruit was probably due to the low humidity and high transpiration (18), as they shrivelled very badly, much more than the following pickings. Shrivelled fruit rarely breaks down.

Even in advanced specimens the pit lesions can usually be detected, as they tend to be surrounded by a white halo contrasting with the brown broken-down tissues (Fig. 2).

There is little doubt that bitter-pit breakdown is one of the important forms in exported apples. In local storage it is of less importance, as very pit-susceptible varieties are rarely stored locally in an immature condition, though they are frequently so exported.

4. Low-temperature Breakdown (Soggy Breakdown).

This breakdown has received a considerable amount of attention in North America (Iowa), New Zealand, and Great Britain. As found in the two former countries (16 and 18) it is typically developed at temperatures below about 38°, and especially below 35°. It appears to be limited to apples grown in climates with relatively low temperatures, low sunlight, and high humidity (8). Susceptibility is not related to size, but is increased by the maturity of the fruit when stored. English experimenters (9) have obtained inconsistent results in regard to the maturity relation, a fact which, as already stated under

immaturity breakdown, suggests that low temperature has not been the only factor operating in their experiments. We do not feel inclined to accept as low-temperature breakdown all forms which develop at low temperature, but confine it to that developing in normal fruit under normal storage conditions. If the storage atmosphere or the pre-storage condition of the fruit is abnormal, surely the primary factor is one or both of these, and not the temperature; in other words, low-temperature breakdown is one controllable in sound mature fruit, under normal storage conditions, by temperature regulation only.

Low-temperature breakdown has been recorded in England (6 and 11), in King Pippin, Blenheim Orange, Bramley's and Lane's Seedlings, &c. King Pippin is very susceptible, Bramleys moderately so, and Newton Wonder highly resistant. In Iowa, United States of America, it has been found in Grimes, Wealthy and Golden Delicious, while Jonathan is apparently immune (14 and 16). In New Zealand (Nelson district), it has been recorded in Sturmer and Cox's Orange Pippin, and also apparently in Jonathan and Dunns, though in these latter the evidence is not so clear cut. Tiller (19) considers the following minimum storage temperatures desirable:—Cox's Orange Pippin and Sturmer 38°, Jonathan and Dunns 35°. It has been stated (9) that the breakdown recorded in Victorian Jonathans is due to low temperature, but with this we cannot agree (see immaturity breakdown). It is also possible that other factors than low temperature have operated in the New Zealand Jonathans and Dunns, especially in view of the apparent immunity of Jonathans in North America.

We have had no experience of low-temperature breakdown in Western Australia, nor have we any definite evidence of its occurrence elsewhere on the Australian mainland. Jonathans in 1929, in Western Australia, picked at fortnightly intervals, developed no more breakdown after 6-7 months' than after ten weeks' cold storage, and most of this could be definitely attributed to water-core and bitter-pit. Breakdown in Dunns in 1929, after 6-7 months' storage, could be directly attributed to immaturity, in direct contrast to New Zealand experience with this variety (18). Jonathans in Western Australia, in 1930, developed considerable breakdown after ten weeks' storage, but the greater part could be directly related to water-core and bitter-pit. Low-temperature breakdown is not known in Jonathans or other varieties in Western North America, where the summer climate approaches that of the Australian mainland. What was probably true low-temperature breakdown developed, in 1929, in experiments with Cox's Orange Pippin in Tasmania, the climate of which is nearer to that of the Nelson district, New Zealand, than that of the Australian mainland.

Cox's Orange Pippins (Huonville, Tasmania). Stored 30-36°

Picked.	Days Stored.	Percentage Bitter Pit.	Percentage Breakdown.
	%	%	%
19.2.29 ..	108	52	23
4.3.29 ..	95	62	13
18.3.29 ..	81	15	39
3.4.29 ..	65	5	50

An undetermined proportion of the breakdown in the earlier pickings was certainly due to bitter-pit, while in the latter it was most probably due to low temperature. This variety incidentally is the most susceptible in New Zealand.

On the available evidence there is, therefore, little reason to suspect the occurrence of this form of breakdown in locally-stored fruit on the Australian mainland, though it may, and probably does, occur in Tasmania. In exported fruit, owing to the relatively short period the fruit is held in refrigerated holds, and the still shorter period below a mean of 37°, low-temperature breakdown is still less likely in mainland fruit, and is probably unlikely even in Tasmanian fruit.

5. Deep Scald.

This is also known as soft scald, but the former name is preferable (19), as it more clearly distinguishes this trouble from superficial or common scald. It may be regarded as a breakdown localized in the tissues of the affected fruit, though it may sometimes develop into a general breakdown. Normally, an affected fruit shows one or more dark and sharply defined depressions running at right angles to the core axis of the fruit, and situated about the middle of the cheeks or on the calyx half. Though starting at or near the surface, the browning of the tissues extends well into the fruit. It is thus readily separated from superficial scald, which does not penetrate the flesh, and does not form sharply depressed areas on the skin.

Deep scald is only developed at low temperatures, i.e., below 36° F., and principally at 32° or lower. It usually develops early in the storage period, but may still be appearing at the end of eight weeks (19).

Susceptibility decreases with the maturity of the fruit after a certain stage or condition of the fruit has been reached (see experiment with Jonathan from Harcourt, Victoria, under immaturity breakdown). Jonathan appears to be the most susceptible variety, but it has been recorded also in Rome Beauty, North-western Greening, Wealthy, and Blue Pearmain in North America (15). It has also been recorded on Rome Beauty and Stone Pippin in Victoria (1). In Western Australia we have found it occasionally on Dunns, and only very occasionally on Jonathans. In our experience it has occurred only when fruit has been placed close to the inlet ducts of battery-cooled stores, where the incoming air temperature was probably below 30° F.

Reports from England (6 and unpublished) indicate that it is not an important defect of exported Australian apples. It has been serious in experiments with Jonathans in Victoria stored at 32-34° F. This has there led to the adoption of 37° by commercial stores as a suitable temperature for this variety (7). In Western Australia, its rare occurrence has not affected commercial storage temperatures, which are usually held around 33-34° F.

No theory of causation has been generally accepted (6), and owing to its undoubted association with low temperatures we have provisionally associated it with low temperature breakdown. A consideration of the facts, however, suggests a line of investigation which might be followed up in places where apples are relatively susceptible. The suggestion is that deep scald and crinkle may have their origin in strongly developed water-core, especially that type developed in

immature fruit, which we have elsewhere distinguished as immaturity water-core (see page 177). We have found that crinkle is caused by the action of heat waves on severe water-core, and it is suggested that deep scald may be a similar response of similarly affected apples to cold waves, i.e., periods with temperatures round about 28-34° F. In support of this suggestion it may be noted that the lesions in both crinkle and deep scald have a general close resemblance both in their character and position. Further, Rome Beauty and North-western Greening have been known to develop both immaturity water-core and crinkle in North America (3), while we have found both in Western Australia in Dunns, Rome Beauty, and Jonathan. As already stated, these varieties are all subject to deep scald. Stone Pippin is subject to water-core, according to McAlpine (12). We do not know whether it gets crinkled or not.

Should this suggestion eventually prove to be true, it would explain some of the peculiar occurrences in the Victorian experiments already referred to (see pages 172 and 173). The effect of increasing maturity in decreasing the incidence of deep scald would fit in with our observations on immaturity water-core. This we have found tends to disappear in varieties like Dunns and Tasma, as the fruits ripen on the trees or at ordinary temperatures after picking. In Jonathan its place is taken by the less severe maturity water-core, which increases as the fruits ripen on the trees.

6. Freezing Breakdown.

Apples which have been frozen are very subject to breakdown. Freezing is rarely serious in exported fruit or local storage, and when severe is usually the result of an attempt to reduce the temperature too rapidly. In exported consignments it is not uncommon but not plentiful, and usually occurs in cases "situated at the points at which the cold air enters the hold or at places where the fruit is exposed to the cooling action of brine grids on more than one side." (6)

7. Water-core Breakdown.

Though the fact that water-cored apples are subject to breakdown is well known elsewhere (4 and 13), the important part that water-core may play in causing wastage in exported or locally-stored Australian apples, appears to have been overlooked. As already stated under deep scald, water-core is of two types. The first is developed in immature fruit and involves more or less of the core. It is generally more severe, but less common than the second type and tends to disappear as the fruit ripens. The second type develops in maturing fruit and does not involve the tissues within the core line of vasculars. This form tends to affect an increasing proportion of the apples of susceptible varieties as they ripen, but the amount in each apple decreases with the increasing maturity of the fruit at the time of its incidence. It is the common occurrence of the second type in varieties like Jonathan and Delicious which had led to the advice that the occurrence of water-core is evidence that the fruit has arrived at picking maturity (13). This advice certainly does not apply to the first type of water-core, which may occur upwards of five months before the normal picking date. The immaturity type often shows as waterlogged patches on the skin which are frequently beaded, especially in the early morning, with drops of sugary sap, while it is rare to get any definite surface indication of the presence of the maturity type.

Water-core slowly disappears in storage, the amount remaining depending, apparently, upon the original amount present and the length and temperature of storage. The higher the temperature, the more rapidly it disappears. With its disappearance, the fruit may return to normality or may breakdown either in store or when removed. What the conditions are which determine whether the fruit will recover normality or breakdown are unknown at present, but it is probable that the humidity of the store may play a part.

From our experiments, it appears that fruits which still contain water-core when removed from store are particularly liable to breakdown.

If, as is probable, the occurrence of breakdown in water-cored tissues or following water-core is the result of abnormal respiration under conditions of reduced air movement in the tissues caused by the sap in the intercellular spaces, the effects of time and temperature in cold storage, given equal amounts of water-core to start with, may be as under:—

1. Short storage at low temperature (35°). Low rate of recovery in store, little or no breakdown in store and high incidence of breakdown afterwards.
2. Short storage at high temperature (40°). Higher rate of recovery in store, some breakdown in store and lower incidence of breakdown afterwards.
3. Long storage at low temperature. Greater recovery in store than (1) and lower rate of breakdown in store or afterwards.
4. Long storage at high temperature. Relatively high recovery and occurrence of breakdown in store, but little or no breakdown afterwards.

Brooks and Fisher (4) have investigated the effect of storage on water-core. They found that Arkansas and Winesap made a better recovery than Rome Beauty, Delicious, and Jonathan, and that small apples made a better recovery than larger. Affected apples had a high but variable degree of susceptibility to breakdown.

Our experience with this type of breakdown has been almost confined to Jonathans, though it has been once noted in Granny Smiths with immaturity water-core. With Jonathans, it was found in our storage experiments in 1929 and 1930. The water-core could be recognized in many of the fruits which developed breakdown even when the latter was well advanced. In every case, it was of the maturity type. When the apples were cut, the water-core could be readily detected as sharply-defined areas associated with the vasculars (Fig. 3). They were translucent and water-white to dark-brown or almost black in colour, contrasting sharply with the lighter brown of the breakdown in the other tissues. Not all the apples with breakdown had recognizable water-core, but there is little doubt that many not so affected, probably the majority, had had water-core and had recovered. In spite of the recovery, the tissues were probably so weakened as to be predisposed to breakdown, as suggested by Brooks and Fisher (4).

The Jonathan storage experiments were made with fruits from the same trees in both years. The crop in 1929 on these trees was heavy, averaging about 12 bushels per tree. In 1930 the crop was very light and the average about 2 bushels per tree. In the former year the fruit

was of excellent shape, colour, and keeping quality. In the latter, the shape tended to be irregular, the colouring weak, and the keeping quality much inferior.

Typical fruits were cut and examined at each picking. In 1929 maturity water-core was first noted on 19th February, in the more advanced fruits, under 5 per cent. of the crop being affected. By 19th March 30-40 per cent. were affected, though not severely as a rule. The figures given below show the breakdown which developed after ten weeks at a mean temperature of 34-36° F. and two weeks in a well-ventilated shed, the fruit being stored within 24 hours of picking. For comparison, the results obtained with duplicate lots stored 6-7 months in the same store and also kept two weeks at ordinary temperature are given. After the first ten weeks the cold storage temperature averaged 33° F.

Jonathan Apples (Karragullen, W.A.) (in Cold Store).

Picked.	Approximate % Water Core When Picked.	% Breakdown after 10 weeks.		% Breakdown after 6–7 months.	
		2¼″	2¾″	2¼″	2¾″
	%	%	%	%	%
19.2.29 ..	5	1	8	Nil	..
26.2.29 ..	10	Nil	3	Nil	2
5.3.29 ..	10	1	2	2	..
12.3.29 ..	15	2	10	2	8
19.3.29 ..	35	2	5	4	..

The importance of water-core was not recognized at the time, and its presence or absence was not noted in the fruit with breakdown except when quite obvious. Bitter-pit breakdown was not found, and there is little doubt that water-core was the principal cause of breakdown. It will be noted that the 2¾-inch size was more affected than the 2½-inch, and that no increase occurred as the result of long storage.

In 1930 water-core was much more plentiful in the fruit, and undoubtedly was the major cause of the serious wastage which subsequently developed.

Portion of the fruit was stored eight weeks at a mean temperature of 33° and held three weeks at ordinary temperatures before the final examination.

Jonathan (Karragullen, W.A.). After eight weeks' storage at 33° F.

Picked.	Approximate % Water-core when Picked.	% Bitter-pit Total.	% Bitter-pit and Breakdown.	% Water-core and Breakdown.	% Breakdown Undetermined.
	%	%	%	%	%
30.1.30 ..	? under 5	5	1	3	Nil
13.2.30 ..	10	2	2	5	4
27.2.30 ..	60	Nil	Nil	22	11

The following gives the results obtained with the remaining lots of fruit which were stored eight weeks in a well-ventilated shed.

Jonathan (Karragullen, W.A.). After eight weeks at 50-90° F.

Picked.	% Bitter-pit Total.	% Bitter-pit and Breakdown.	% Water-core and Breakdown.	% Breakdown Undetermined.
	%	%	%	%
30.1.30	6	Nil	Nil	3
13.2.30	11	7	3	5
27.2.30	Nil	Nil	11	5

Very little breakdown occurred in cold store, but it developed rapidly after the fruit was removed to ordinary temperatures. It is evident that the method of storage had little effect on the development of bitter-pit breakdown. With water-core breakdown, there was a considerable reduction in shed as against cold storage. Probably both the higher temperature and lower humidity of the former operated to this end. All the shed-stored fruit was cut up and no water-core was found except in those with breakdown, indicating a definite recovery from this defect. The following figures show the distribution of the breakdown in the two types of storage in 1930:—

—	Total Breakdown %.	% Breakdown due to—		
		Bitter-pit.	Water-core.	Undetermined Causes.
	%	%	%	%
Cold Store	14	8	62	30
Shed	10	22	37	41

There was slightly more breakdown in the 2¾-3-inch fruit than in the 2¼-2½-inch. Undoubtedly a large proportion of the undetermined breakdown was due to water-core which had disappeared, though a little appeared to follow case bruises. The unaffected shed-stored fruits of the last picking kept in excellent condition for eight weeks, although, judging on the colour of the non-flushed skin, they were at least as ripe as those showing breakdown. In other words, there was no evidence of over-maturity breakdown. This was also the case in 1929. The shed-stored fruit of the first and second pickings in 1930 shrivelled badly, and were not in good commercial condition after eight weeks.

It is evident that the presence of water-core in apples may have a marked effect on their storage life. We have no reason to doubt that those used in 1929 and 1930 were typical of the variety in Western Australia in those years. Whether Jonathans in the other States are equally liable to water-core we do not know, but, as pointed out under immaturity water-core, published Victorian experiments certainly suggest that this defect may be at times serious in that State. Brooks and Fisher's figures (4) indicate that the amounts found in our experiments are not exceptional in North America. The difference in the amounts in 1929 and 1930 may be partly related to the difference in the size of the crops, and very probably to the occurrence of exceptionally high temperatures in January and February of the latter year.

8. Gas Breakdown.

This name is suggested for breakdown caused by abnormal storage atmospheres, particularly the form known as brown heart. Since the accumulation of carbon dioxide in the storage atmosphere has been shown (17) to be the cause of this defect, controlled ventilation has become part of the routine of shipping apples in refrigerated holds. As a consequence, brown heart is no longer an important cause of wastage. In land stores, sufficient ventilation is obtained with less trouble. They are rarely filled as completely as a ship's hold, and are frequently opened for inspection or the movement of fruit in or out. The carbon dioxide in holds and stores has its origin in the normal respiration of the fruit.

Investigations are proceeding in England (10 and 11) to test the possibility of increasing the storage life of apples by deliberately altering the storage atmosphere, mainly by decreasing the oxygen and increasing the carbon dioxide. Very striking and promising results have been obtained. It has been found, however, that there are limits to such alterations of the storage air at low temperatures imposed by an increased susceptibility of the fruit to breakdown.

9. Bruising Breakdown.

Injury and death of the tissues following bruising appears to predispose apples to breakdown. This we have noted in Jonathans. Usually, however, such fruit succumbs to fungal rots before breakdown sets in.

3. Conclusion.

In conclusion, it is evident that much work has yet to be done before the relative importance of the forms of breakdown developing in Australian apples, both locally and when shipped overseas, can be definitely stated. This work must involve a knowledge of the pre-storage condition of fruit used in storage experiments.

In our experiments, water-core and immaturity have been responsible for most of the breakdown observed. That due to immaturity has been of two types, one apparently due to immaturity *per se*, and the other developing in consequence of bitter-pit, itself a product of immaturity. Low temperature breakdown probably occurs in Tasmanian fruit stored at 30-40°, but there is little evidence of its occurrence in mainland fruit. Over-maturity breakdown is apparently relatively unimportant, especially in overseas shipments.

It is hoped that these notes will lead to investigations in the several apple-growing States, as definite knowledge of the types of breakdown likely to be important is fundamental to the prevention of wastage from breakdown in exported apples.

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PLATE 1.

FIGURE 1.—Dunns Apples. Breakdown associated with immaturity.

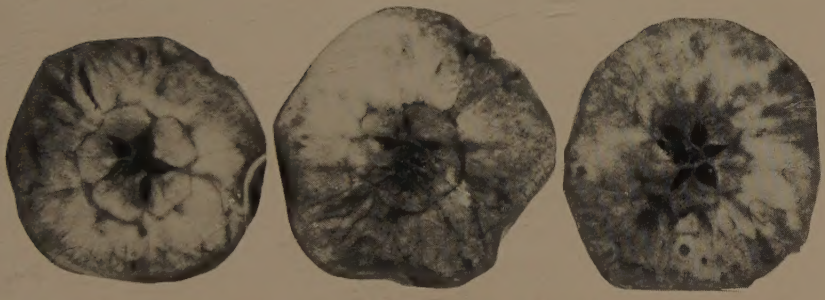

FIGURE 2.—Jonathan Apples. Breakdown associated with bitter pit. Note the white ring around some of the pit lesions.

FIGURE 3.—Jonathan Apples. Breakdown associated with water core, which appears almost black in the photo. Note its association with the vasculars.

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